The Hydrogen Test Facility's Composite Disk Permeability Testing

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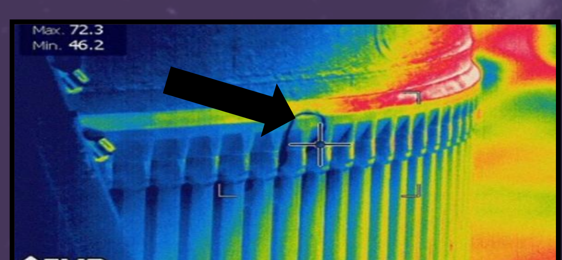
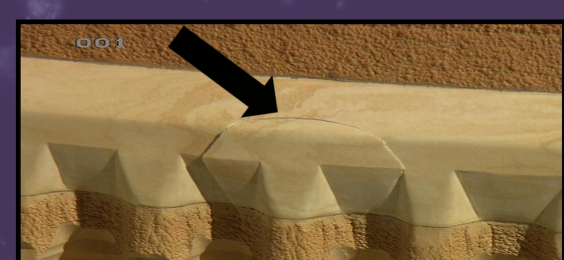
INTRODUCTION

NASA developed the Composite Cryotank Technologies Demonstration Project in order to explore composite materials that would reduce the overall cost and weight of liquid hydrogen cryotanks. Composites were selected because they are much lighter than aluminum, which currently composes the shuttle's external tank. However, micro-cracking was observed when these materials were exposed to a cryogenic environment. Permeability testing became a part of this program because it provides a way to study these micro-cracks and the dangers they present to the spacecraft and its surrounding environment.





The pictures shown above are cracks observed on the external fuel tank of the Discovery Space Shuttle months before launch in December 2010.

Permeability tests condition different carbon fiber reinforced polymer specimens at cryogenic temperatures under biaxial loading in order to simulate a realistic space-like environment. The tests focus on thin ply composites because they have shown the least micro-cracking in the past, and they would be a likely candidate for a future space craft's cryotank.

BACKGROUND

Liquid hydrogen, LH_2, is an extremely valuable fuel source for many vehicles, ranging from rockets to automobiles. It is presently being used as a propulsion fuel and as a means of generating electrical power in the space shuttle. However, hydrogen is severely hazardous. Because it is cryogenic (boils at temperatures below -265 °F), safety precautions must be taken when working around this element. Once the liquid hydrogen boils at -423°F, it becomes a gas that is invisible, flammable, and easily-ignitable. It is for this reason that hydrogen must be contained in the shuttle's fuel tanks and that these tanks do not experience much cracking or, in other words, become permeable.

The CECE (Common Extensible Cryogenic Engine) at different throttle levels. It burns hydrogen and oxygen that are stored as extremely cold cryogenic liquids in insulated tanks.

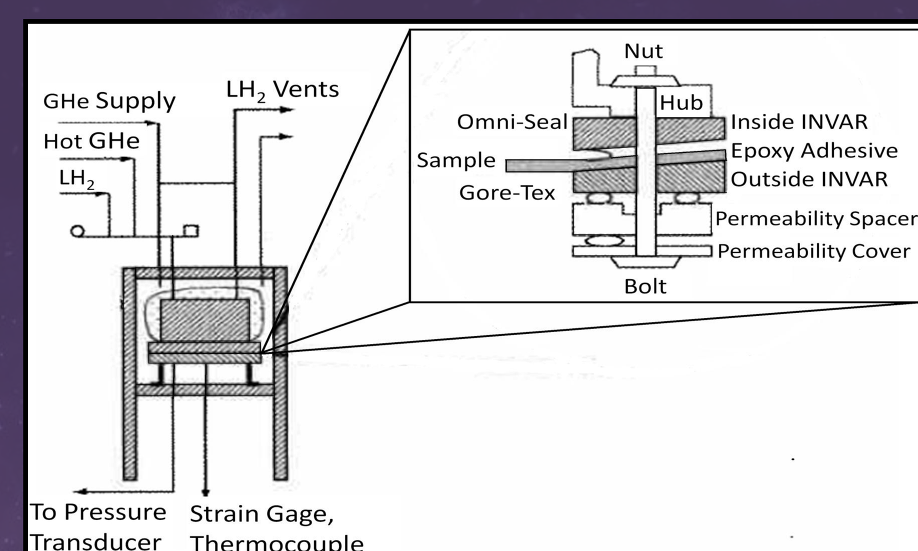
Permeability is defined as the flow of a liquid or gas through a porous material. It is important to measure this flow rate for different materials so that the best candidate for future fuel tanks can be identified. Most composite materials would qualify for flight on a space shuttle before they undergo cryogenic testing. However, when the carbon fiber composite comes into contact with the extremely cold liquid hydrogen, the material isn't completely solid anymore, and it leaks. So, the final selection of the composite is based on how the material performs after a certain degree of thermomechanical cycling.

OBJECTIVES

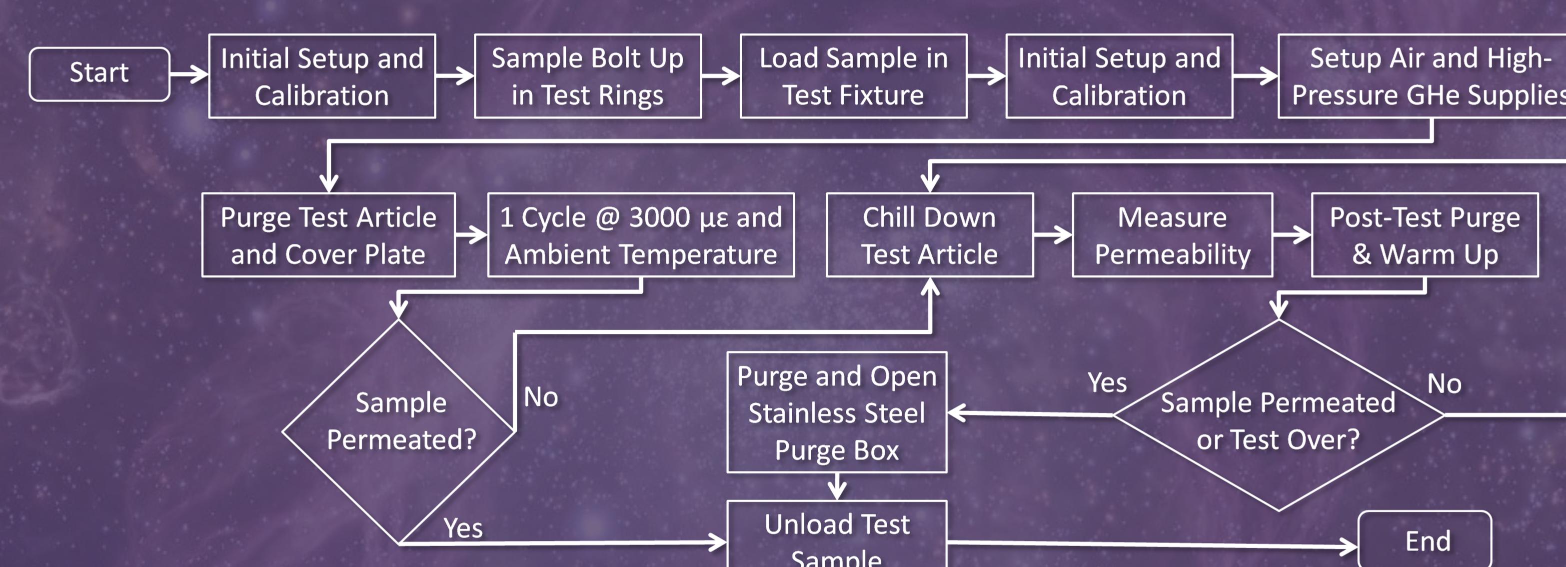
- To perform mechanical tests that determine a composite material's properties in extreme environments, including cryogenic and high-pressure liquid hydrogen and gaseous helium.
- To evaluate the permeability of several samples after cycling in a cryobiaxial environment (-400°F and 5000 microstrain with a 1:1 average strain field).
- To provide new, safe, and innovative cryotank technologies that enable human space exploration to destinations beyond low Earth orbit.

METHODOLOGY

The test frame consists of a hub, a set of Invar rings, a cover plate, an instrumented composite disk, a mass spectrometer, and a data acquisition system. The test's setup and procedures are shown below.



The cryobiaxial permeability apparatus.



The test's flow diagram.

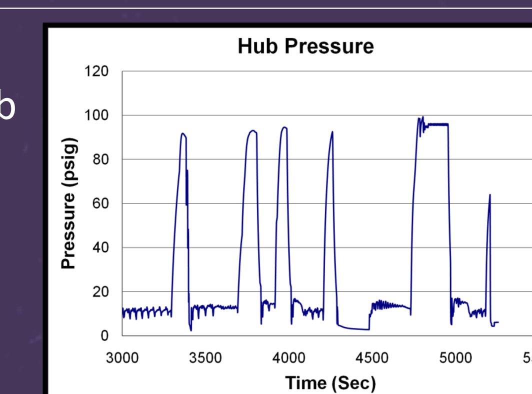
A composite disk.

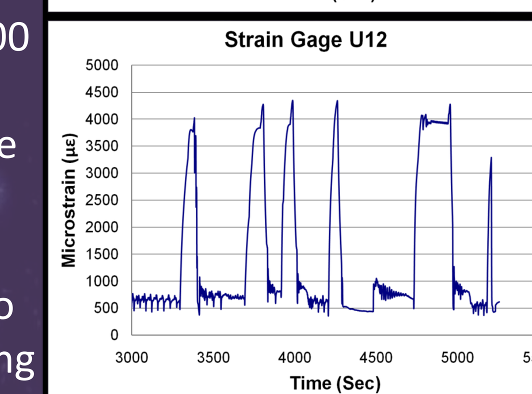
Different composite materials and epoxy adhesives were used to form the individual sample disks, however, the procedure for testing each of these disks remains the same. In preparation for testing, the composite panel was bolted to a ring fixture made from Type 304 stainless steel. Sixty bolts passed through the upper Invar ring in order to secure the test fixture.

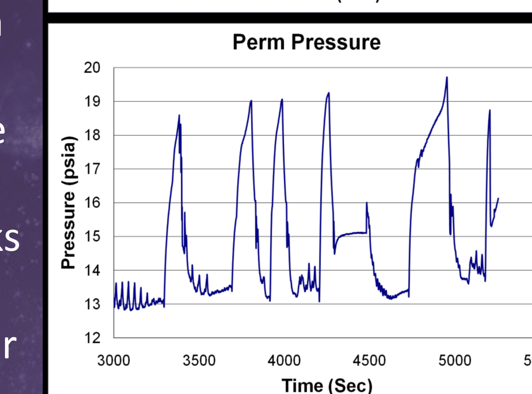
The sample was then loaded into the test frame. All of the thermocouples and strain gages on the disk were plugged into their corresponding channels of the data acquisition system and calibrated. Once the calibrations were verified, the sample was tightened further into the frame. Then, the gaseous helium supply was turned on to purge the test article and the cover plate. Purging the box ensures that the entire system is leak tight and that no leftover hydrogen is still in the system. After performing the pre-test setup, the hub space was filled with liquid hydrogen. Each sample disk was then put through a series of thermal cycles. A thermal cycle consists of cooling the panel to cryogenic temperatures, applying one or more mechanical strain cycles, and then returning the panel to ambient temperature (room temperature). Each sample was tested until it permeated or until all six thermal cycles were completed, whichever came first.

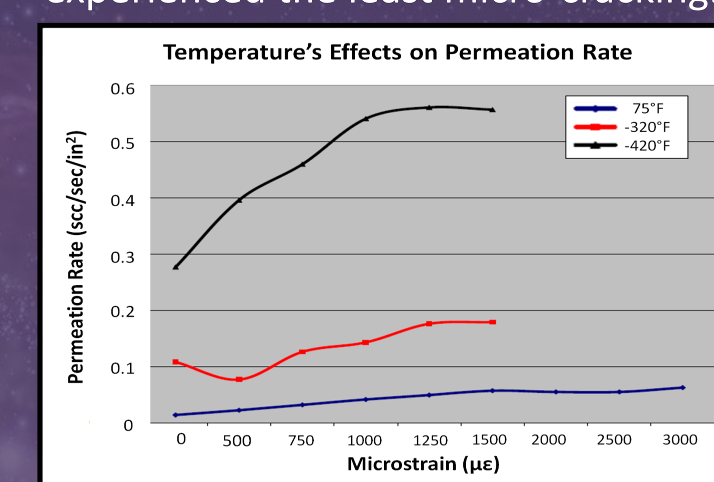
RESULTS

After testing several composite disk samples, it was apparent that the hub pressure, ply thickness, strain, and temperature contributed to the specimen's permeability. As the hub pressure was increased, the biaxial strain also increased. When the disk was cycled at high strains around 4000 με, the disk usually permeated. Permeation occurs when the pressure of the perm space rises over atmospheric pressure (around 14.7 psia). This pressure increase is due to an added volume of hydrogen entering the perm space. Hub pressure, perm pressure, and strain all increase proportionately over time. The three graphs to the right accurately depict this proportional increase. Most disks permeated, but those made of IM7/977-2 0.0025 in/ply carbon fiber experienced the least micro-cracking.









Temperature also had an effect on a composite's permeability. The more a disk was cooled, the more it experienced micro-cracking. The most permeation occurred at hydrogen's cryogenic temperature, -423°F.

CONCLUSION

Permeability testing has not had the opportunity to screen all methods of constructing thin ply composites. With further testing, the problem of micro-cracking, which is directly linked to hydrogen fuel loss, will be solved. Once the material with the best performance is found, it will be possible to invent a new cryotank technology that will take humans to Mars and beyond.

FUTURE WORK

- To investigate permeability tests that require more relevance to on-pad and in-flight loads.
- To further explore the reasons for performance separation between the different composite materials.
- To determine an efficient way to locate the micro-crack/failure

REFERENCES

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